HTS-multichannel-system for magnetocardiography and magnetoencephalography

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1 Introduction

A new, small biomagnetic system with 8 channels operating at 77 K has been constructed. In the gantry inside the magnetically shielded room it can be shifted to five positions so that up to 40 positions can be measured successively. We employ low noise dc-SQUID magnetometers from high-temperature superconductors (HTS) to demonstrate mapping measurements of cardiac fields and measurements of somatosensory evoked signals. We compare our signals to measurements on the same volunteer with a conventional Helium cooled system based on dc-SQUIDs.

2 Methods

2.1 Sensors

As sensors we employ directly coupled dc-SQUID magnetometers based on symmetric 24° and 30° $SrTiO_3$-bicrystal substrates with all wide $YBa_2Cu_3O_7$ lines perforated with holes to reduce vortex-induced low frequency noise when operated in static magnetic fields. Our HTS-dc-SQUIDs achieve a magnetic noise level below 50 $fT/\sqrt{(Hz)}$ at 10 Hz. The magnetometers are designed for operation in earth magnetic field without increase of the low frequency noise [1]. The linearity of integrated HTS-dc-SQUIDs in electronic gradiometers is crucial for the operation in unshielded environment. The sensors are encapsulated for protection against moisture and icing during warm-up. The housings also contain a heater and the feedback-coil for flux-locked loop operation. The magnetometers allow the detection of low lying sources. These signals could be reduced by wire-wound gradiometer arrangements with fixed length, as used in the convent6ional niobium system.

2.2 HTS-multichannel-system

The sensors are mounted in a small, mobile cryostat with an outer diameter of 140 mm, a length of 400 mm, and a distance of about 30 mm between the outside of the cryostat and the sensors. This rather large distance results from our glass cryostat which reduces the cryogenic system costs to below 500US$. The dewar dimensions are comparable to our handheld dc-SQUID system [2]. But here the cryostat contains 1.5 l liquid nitrogen resulting in a measurement time of up to 40 hours. The cool down is done in about 5 minutes. The complete system with the electronics in the background is depicted in Fig. 1. Here, for the use in shielded environment only the bottom plane is equipped with 8 sensors. As electronics we use an 8 channel commercial electronics from PHILIPS with ac-bias and flux modulation at 250 kHz. The analog signals are digitized and evaluated with the same set-up as the niobium system. The mapping is calculated using the CURRY software of NEUROSCAN with a bandwidth of the software filter of 70 Hz.

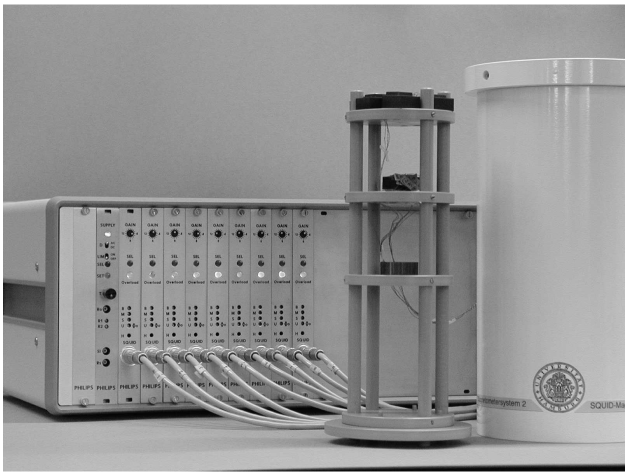

Figure 1: *Photograph of the HTS-multichannel system. The cryostat is about 40 cm high.*

2.3 Measurement configuration

The cryostat with 8 magnetometer channels is mounted in a gantry where it can be shifted horizontally to five positions. This results in 40 sensor positions for magnetic field mapping measurements. The arrangement is shown in Fig. 2.

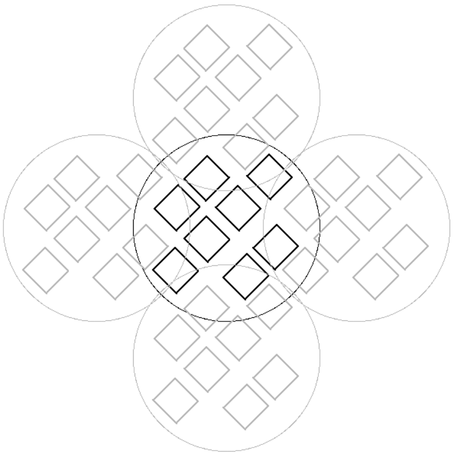

Figure 2: *Sensor arrangement in the five positions of the cryostat. From the central position the cryostat can be shifted by 6 cm to 4 further positions.*

The niobium system consists of 31 gradiometer sensors mounted with constant radius on a shell. It has been described in detail in [3]. The MCG-measurements were made with ECG-trigger to correlate the relative time scales of the five system positions. After measuring for 120 s the time traces were averaged and for every time step the field map was calculated.

For the MEG-measurements one of the authors volunteered. Using an electric stimulus of the nervus medianus at the left hand of 4 mA at 2 Hz, evoked fields have been recorded, as demonstrated below.

3 Results

3.1 Demonstration of cardiac field mapping

With the HTS-System the cardiac time traces were recorded for 120 s in every position. In Fig. 3 the averaged time traces of the 8 sensors for all five positions are shown.

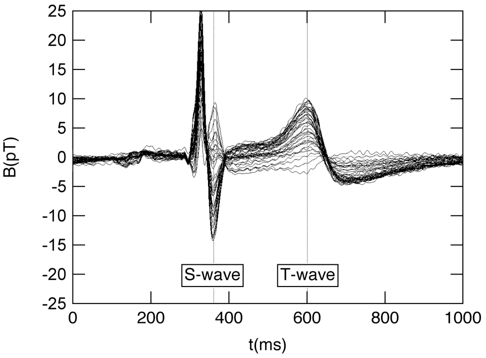

Figure 3: *Time traces of the 40 filtered channels after accumulation for 120 sec.*

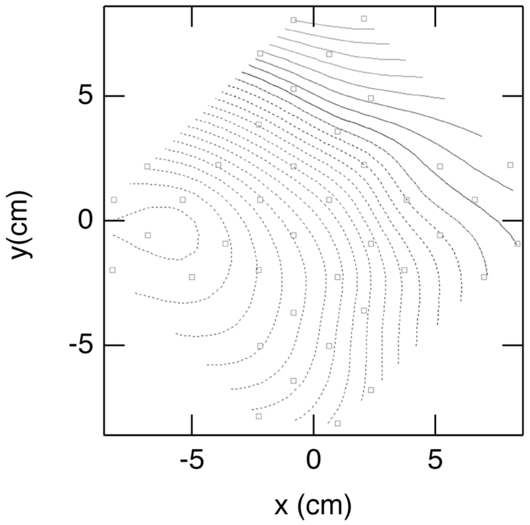

Figure 4: *Corresponding field map at the time of the S-wave. The map covers an area of about 147 x 131 mm^2.*

We find signal amplitudes of about 25 pT. The corresponding field mapping at the time of the S-wave is depicted in Fig. 4.

3.2 Electrically evoked magnetoencephalographic signals

On the same volunteer we then recorded electrically evoked fields as reaction of the stimulation of the median nervat the left hand. The signals of two channels are shown in Fig.5 at different measurement positions with a bandwidth of 500Hz (thin line) and 200 Hz (thick line) after 2000 averages. The two signals show the positive and negative field components of the stimulated activity. The stimulation took place at 0 ms.

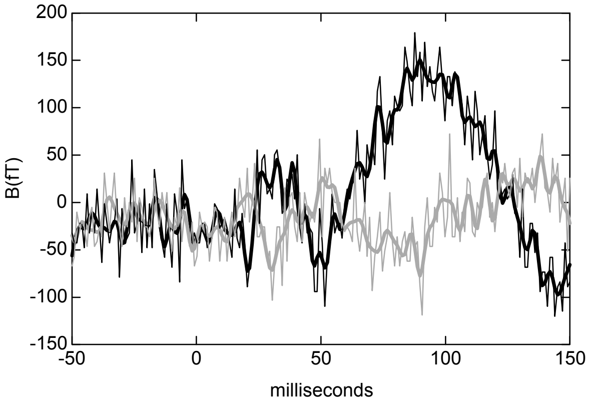

Figure 5: *MEG-signals of the elctrically stimulated nervus medianus at two different positions, recorded with the HTS-system.*

4 Comparison of the two systems

4.1 MCG

To compare both systems we first treat the measured MCG data. Two typical magnetocardiograms are shown in Fig. 6 after averaging for 120 s with a bandwidth of 500Hz. The solid line is a magnetometer-signal from our HTS-system, the dotted line is recorded with a gradiometer of the niobium-system.

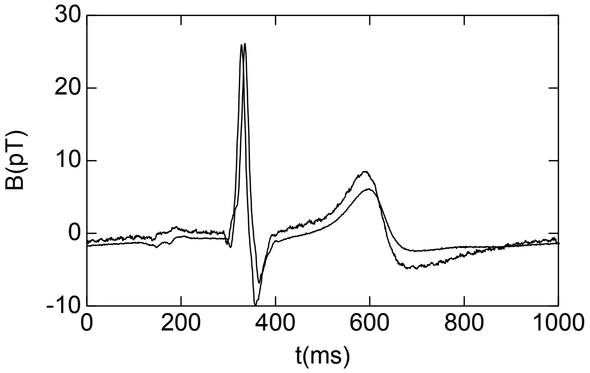

Figure 6: *Comparison of the recorded MCG data of the HTS-system (solid line) and the niobium-system (dotted line).*

Both signals show nearly the same amplitude although the gradiometer signal should be smaller. This is due to the thickness of our glas cryostat and the resulting large distance between the magnetometers and the source.

To illustrate the amount of heart-signal lost by using axial gradiometer arrangements, we recorded a MCG of another volunteer with two of our sensors, one mounted on the lowest level and the other on the middle level, building an axial gradiometer with a baselength of 7cm.

The electronics was set to dc-coupling to proof the as made balance of our gradiometer, which achieves values better than 10^{-2} for low frequencies. In Fig. 7 the two timetraces and their difference are depicted.

Despite of the baselength of 7 cm there is a comparable large heart signal on channel 2 with a maximum amplitude of 10 pT. About a quarter of the signal on channel 1 is lost by subtracting both signals.

Using magnetometers instead of axial gradiometers could be advantageous because of the higher signals that should be obtained.

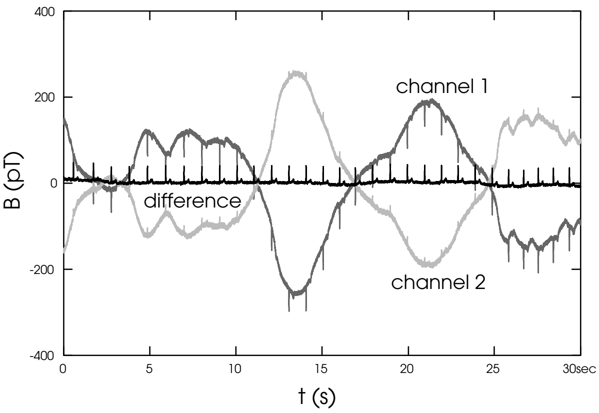

Figure 7: *Heart signals recorded with an axial gradiometer in the HTS-system. Channel 1 is inverted for better overview.*

4.2 MEG

The comparison MEG measurement with the niobium based system after 500 averages is shown in Fig. 8. The peaks found in the traces in figure 8 can easily be recognized in the HTS-system data in Fig. 5. By reducing the distance between the HTS-magnetometers and the outside of the cryostat the amplitudes of the measured signals should become larger, so that less averages will be needed to get reasonable data.

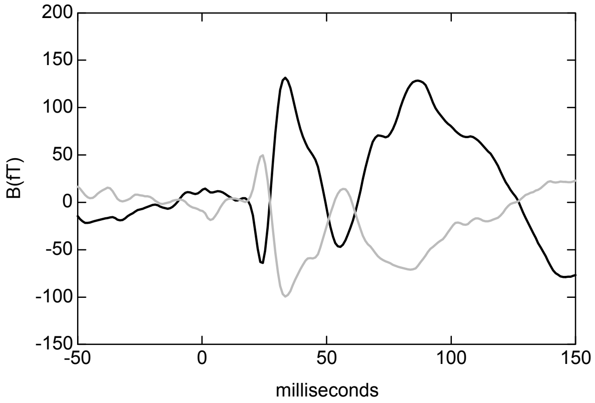

Figure 8: *MEG-signals of the electrically stimulated median nerve at two different positions, recorded with the niobium-system.*

5 Conclusion

We have built a handy 8-channel HTS-system with encapsulated sensors which gives us a great flexibility for sensor arrangement.

The system works stable in shielded environment and allows magnetocardiographic mapping with 40 sensor positions. Magnetoencephalographic measurements of the electrically evoked nervus medianus are shown as well.

The current status allows the use of HTS-dc-SQUID magnetometers for multichannel applications complementing niobium SQUID-systems in applications, where small mobile cryostats in moderately shielded environment are advantageous.

For unshielded environment further measurements are planned.

Acknowledgements

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References

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